Innovative Concept in Brain-Machine Seamless Interface for Human-Robotics Space Development Capabilities

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Introduction

- Beyond the ISS, future missions to the Moon and especially Mars will require an unprecedented level of human performance, exposing humans to the dangers of vacuum and hard radiation, among other dangers.
- These kinds of ambitious flights require a new technical approach that combine the advantages of robotics and human capability.
- This concept will take advantage of recent advances in measuring neurological currents in the brain, robotics and computer science to create a new technology that is an amalgamation of human and machine—a technology that has the potential of addressing the challenging future goals of human space flight.

Project Objective

The objective of this project is to study and provide a proof-of concept that would demonstrate the feasibility of building a servo-driven “Frame” controlled by human thought. The Frame can contain an operator or can be controlled remotely.

Present State-of-the-Art and Capabilities

- Space Flight Hardware has been designed for Human Servicing
  - Substantial Investment in EVA tools
  - Accumulation of Equipment requiring a humanoid shape and an assumed level of human performance and capability
- Space Robotics, system autonomy and AI development has been too focused on specific narrow functional or operational capabilities for a specific mission requirement which made most concepts and products very costly (lack of volume) and inefficient for other applications or missions…..which resulted in minimal impact on progress
- A new technical approach is needed that focussed from the beginning to a “Man-Machine” technology thrust development strengthened by the acquired knowledge in Human Servicing and Space Robotics

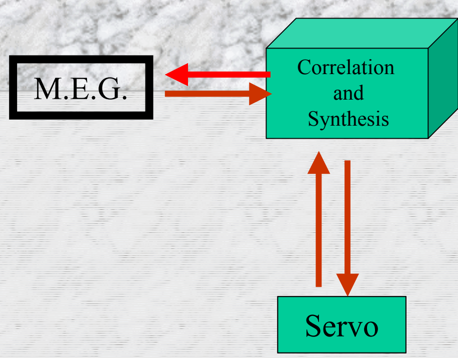
Why Now?

- **Recent Technical Advances in Brain imaging and robotics have made this concept potentially feasible and cost effective**
  - Take advantage of recent advances in measuring neurological currents in the brain, robotics and computer science to create a new technology that is from the beginning an amalgamation of human and machine—a technology that has the potential of addressing the challenging future goals of human space flight.
  - Recent technical and theoretical advances, have demonstrated the ultimate feasibility of this concept for a wide range of space-based applications.
  - With the invention of the Superconducting Quantum Interference Device (SQUID), the capability has been at hand to measure neurological currents at a level of a million times less than that of the Earth's magnetic field. A new low-cost medical instrument which measures brain activity using Magnetoencephalography (MEG)

    at millisecond or better scan rates.
  - The U.S. Department of Energy's Los Alamos National Laboratory has unveiled a new low-cost medical instrument which measures brain activity using this technique. This instrument is expected to aid physicians in assessing patients with

    brain injuries and diseases, and to solve the mystery of how the brain works.

Basic Concept



A servo in the suit creates a current that is proportional to the velocity of the user's movement.

The MEG measures the magnetic field currents that the brain produces when the operator moves the servo.

Repeated measurements allow the computer to correlate the specific brain activity associated with moving a single joint.

Using this correlation, the computer can synthesize a current to the servo causing it to operate naturally when the operator thinks about moving the joint.

This effect can be used to either almost instantly amplify the operator's movements or give extremely precise and human-like control to a remote robot.

Note: this diagram contains a photograph of an existing NASA spacesuit and operator for conceptualization purposes only.

The Approach

- The whole-head magnetoencephalography (MEG) sensor system is a method of measuring the tiny magnetic fields that are produced when groups of the brain's 100 billion or so cells (neurons) are active. The fields are generated by electrical currents resulting from thought, sound, muscle movement impulses, and other types of brain activity.
- The helmet-like system contains 155 ultra-sensitive sensors, known as superconducting quantum interference devices (SQUIDS). Atop the device is a unique shield that screens out electrical and magnetic interference, and an instrument column, immersed in liquid helium, that maintains the SQUIDS at -450°F.

Enabling Capabilities

- Increase the strength of human being without the time lag problem in previous concepts. It would be as if the operator had suddenly super strength because the servos would be getting signals directly from the brain.
- The suit could operate without the human being in the suit, controlled remotely by radio. The human controller would merely think about doing an action and the suit would act as he or she were in the suit. The applications to Man-Machine Space Systems are numerous.
- There is no reason this concept could not be applied to mechanisms other than a servo-driven suit, such as an aircraft or spacecraft. This idea has the potential of a practical way for an astronaut to control a robot, either in or out of the spacecraft

Correlation and Synthesis

- Correlation will be implemented using well-known techniques in modeling electromagnetic phenomenon using electric field measurements
- Mathematical modeling has been shown to be a substantial tool for the investigation of complex biophysical phenomena
- The use of this technique is simpler in this case since we only require correlation.

Brain Scan Technology- Challenge 1

- Magnetoencephalography (MEG)
  - Similar to EEG in that it picks up signals from neuronal oscillation, but it does it by homing in on the tiny magnetic pulse they give off rather than the electric field. This technique has weaknesses -- the signals are usually weak and there is interference. Yet, it has enormous potential because it is faster than other scanning techniques and can therefore chart changes in brain activity more accurately than fMRI or PET.
  - Magnetoencephalography (MEG) is a non-invasive brain imaging technique that allows physicians and scientists to record and localize millisecond by millisecond, the activity of nerve cells located throughout the brain. Using exquisitely sensitive amplifiers known as Superconducting Quantum Interference Devices (SQUIDS), electromagnetic brain waves occurring during movement, sensation, and cognition can be recorded and accurately mapped to specific sites. Unlike a routine MRI or CAT scan, which shows only the structure or anatomy of the brain, MEG determines the function or physiology as well. This technique has been used to study the mechanisms of consciousness, epilepsy, movement disorders and learning disorders.

Brain Scan Technology - Challenge 2

- The following are the various types of brain scan systems being used today but do not have the fast scan rates of MEG
- Magnetic Resonance Imaging (MRI)
  - Aligns atomic particles in the body tissues by magnetism, then bombards them with radio waves. This causes the particles to give off radio signals that differ according to what sort of tissue is present. A sophisticated software system called Computerized Tomography (CT) converts this information into a three-dimensional picture of any part of the body.
- Functional MRI (fMRI)
  - Adds to the basic MRI anatomical picture by adding to it the areas of greatest activity. Neuronal firing is fueled by glucose and oxygen, which are carried in blood. When an area of the brain is fired up, these substances flow towards it, and fMRI shows up the areas where there is most oxygen. The latest scanners can produce four images every second. The brain takes about half a second to react to a stimulus, so this rapid scanning technique can clearly show the ebb and flow of activity in different parts of the brain as it reacts to various stimuli or undertakes different tasks. fMRI is phenomenally expensive and brain mappers often have to share a machine with clinicians who have more pressing claims to it.

Brain Scan Technology - Challenge 3

- Positron Emission Topography (PET)
  - This technique achieves a similar end result to fMRI -- it identifies the brain areas that are working hardest by measuring their fuel intake. The pictures produced by PET are very clear (and strikingly pretty) but they cannot achieve the same fine resolution as fMRI. The technique also has a serious drawback in that it requires an injection into the bloodstream of a radioactive marker. The dose is tiny but, for safety, no one person is generally allowed to have more than 12 scans per year (this actually equals one scannin session).
- Electroencephalography (EEG)
  - Measures brainwaves - the electrical patterns created by the rhythmic oscillations of neurons. These waves show characteristic changes according to the type of brain activity that is going on. EEG measures these waves by picking up signals via electrodes placed in the skull. The latest version of EEG takes readings from dozens of different spots and compares them, building up a picture of varying activity across the brain. Brain mapping with EEG often uses Event-Related Potentials (ERPs), which simply means that an electrical peak (potential) is related to a particular stimulus like a word or a touch.

Task Elements

- Feasibility Study
  - This proposal outlines the approach and discusses fallback scenarios if the more exotic elements of this project prove problematic. The first task of this project will be to examine each of the proposed step in detail to determine the most likely course of successful development.
- Experiment Design
  - Once a detailed plan has been developed an experimental design will be developed which will include a resource plan for lab space and equipment.
- Correlation software design
  - A key element of this project is the correlation (and synthesis) software. A design will be developed for implementation in ANSI standard C++.
- Preliminary correlation software for test
  - A preliminary version of the correlation software will be developed for integration with a test rig.
- Test using MEG facility
  - A series of integrated tests using a MEG facility will be performed on a human subject. The objective of the test will be to (1) demostration correlation of motor neuological brain activity and (2) demonstrate servo positioning using brain activity alone.
- Applications to NASA programs study
  - A study will be performed to show how direct brain to servo capability can be exploited in two NASA scenarios:
- Lunar , Mars, Servicing, Assembly. Habitats, etc. exploration scenarios